Overview of accelerator R&D at LBNL

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Accelerator Technologies and Applied Physics — ATAP

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The charge provided by the sub panel

1. What are the appropriate goals for medium- and long-term U.S. accelerator R&D required for a world-leading program in accelerator-based particle physics consistent with the scientific priorities outlined in the HEPAP-P5 report?

2. The scope of the current medium- and long-term R&D efforts and how well these address the goals for this program.

3. What is needed to achieve these goals including resources, management of research efforts, and existing and expected expertise and infrastructure?

4. How the training of future accelerator scientists and technologists through accelerator R&D efforts is going?

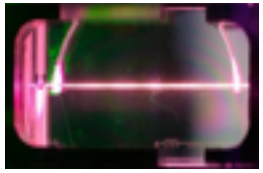
5. With a sufficiently exciting program, it is possible to increase the funding in accelerator R&D. What would be the elements of such a program especially in long-term R&D both at the intensity and energy frontiers?

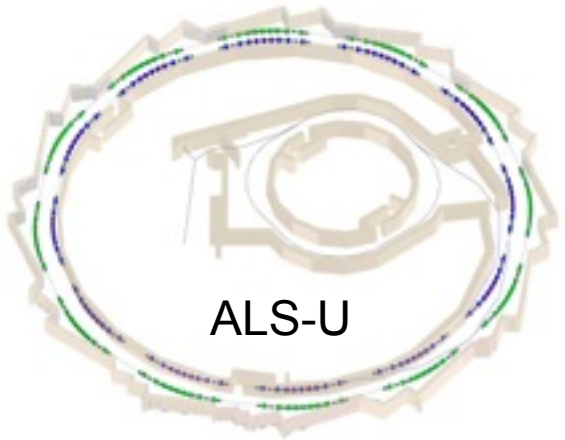
LBNL's programmatic goals and activities align well with P5

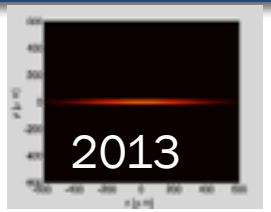
Recommendation 26: Pursue accelerator R&D with high priority at levels consistent with budget constraints. Align the present R&D program with the P5 priorities and long-term vision, with an appropriate balance among general R&D, directed R&D, and accelerator test facilities and among short-, medium-, and long-term efforts. Focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators.

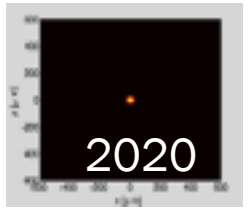
- **Three core thrusts:**
  - Modeling, diagnosing and controlling accelerators:
    - Center for Beam Physics (CBP) and BELLA Center
  - Push the frontiers of superconducting magnets towards higher fields and lower cost:
    - Superconducting magnet program (SMP)
  - Develop compact-ultrahigh gradient, lower cost high energy accelerators:
    - Laser plasma accelerators at BELLA Center
- **One accelerator test facility:**
  - BELLA Center

Building blocks at LBNL are accelerators, lasers, magnets, instrumentation, computation for science and technology

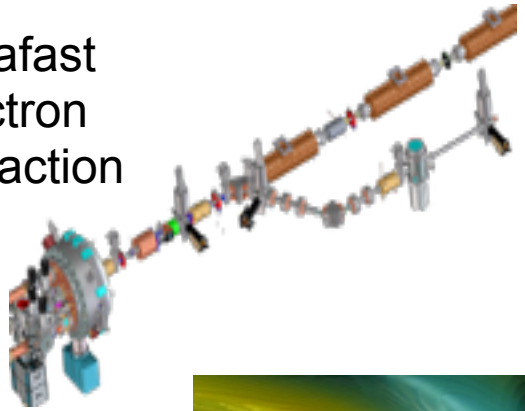


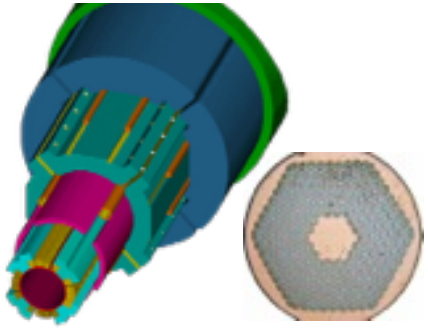




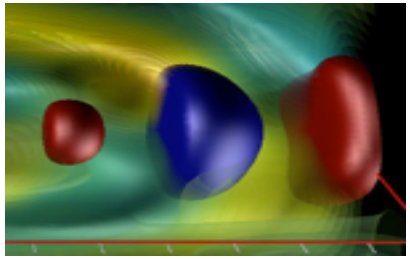


Ultrafast electron diffraction





Superconducting Magnets



High performance computing

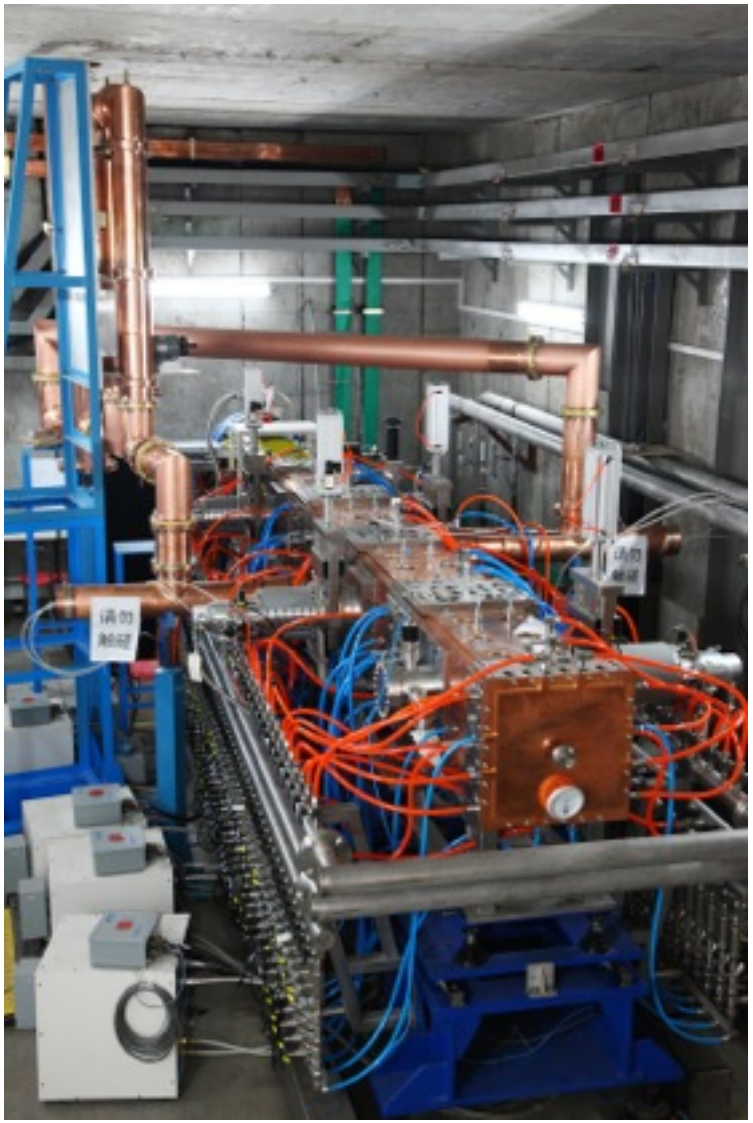
Extensive expertise in RF power provides support to core activities of HEP

Support Fermilab program

- Provide front-end hardware for PIP-II (ion source, RFQ)
- Provide modeling for high intensity proton beams (including LEBT)

Continue support of DOE/HEP LARP program and ramp down of MAP

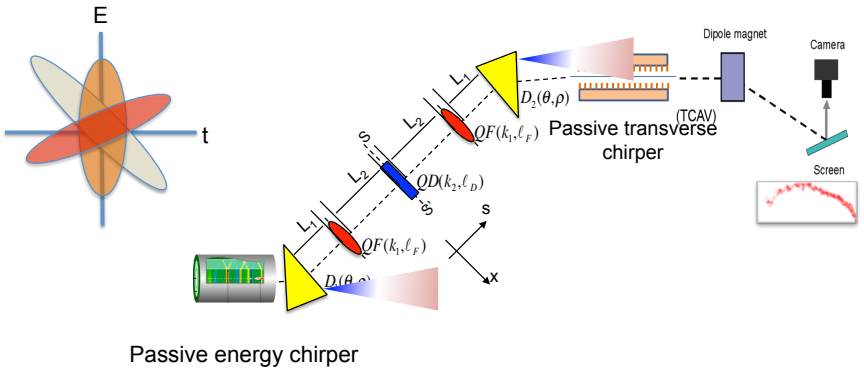
- LARP: lead crab cavity effort, LNC and HL-LHC beam-beam modeling, LHC injector space charge modeling
- MAP: complete MICE responsibilities - step ~4.5



Modeling, diagnosing and controlling accelerators is a key thrust area

- Activities in both CBP and BELLA Center
- Applied to both RF and advanced accelerators

- Beam diagnostics and control systems:
  - Beam loss monitoring for high power beams
  - Phase space manipulation
  - Ultra-precision timing systems
  - See John Byrd's talk

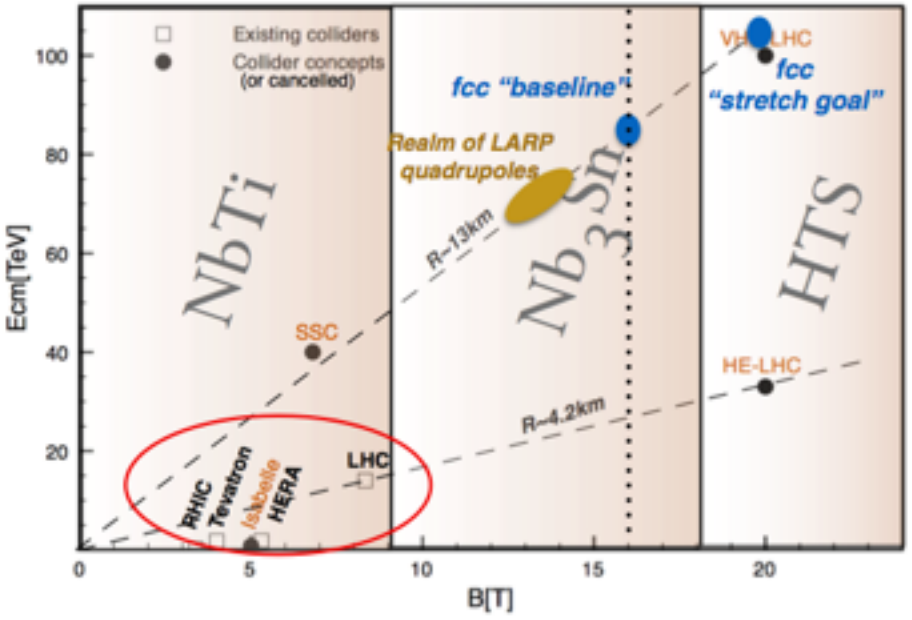


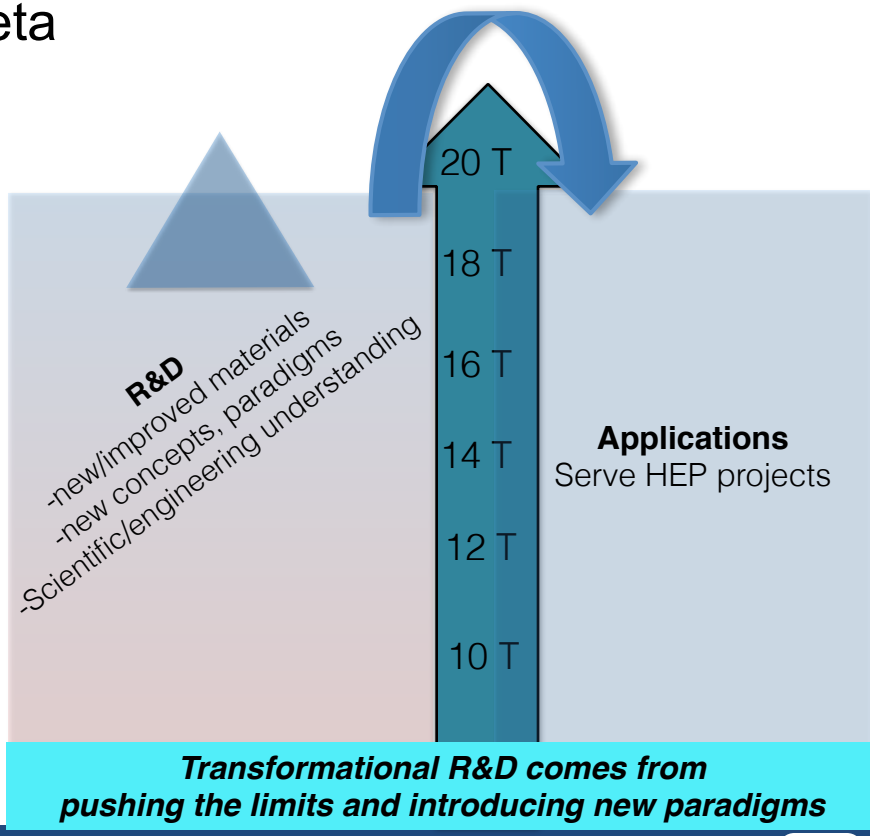
Passive energy chirper

- Advanced modeling:
  - High performance tools to allow fast (near real-time), high fidelity accelerator modeling
  - CAMPA initiative (joint with SLAC and FNAL)

A second key thrust area is to push the frontiers of superconducting magnets for higher fields and lower cost

- Activity in Superconducting magnet program
  - See Soren Prestemon's talk
  - LBNL program has a multi-pronged approach
    - Conductor development
    - Novel geometries - canted cosine theta
    - In-house test facility

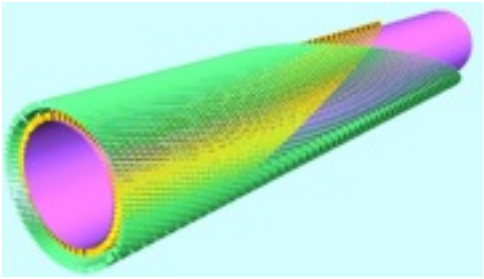




The CCT has the potential to provide record field strengths and lower cost magnets but needs to be demonstrated

Simplicity – better performance

- Robust, reproducible, manufacturable
- Minimal external structure (little or no prestress)
- Modest tooling requirements



Intrinsic Stress Reduction

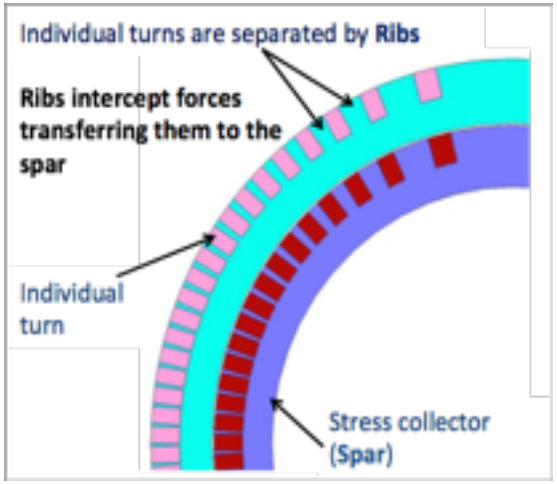
- Allows grading (near optimal conductor efficiency)
- Allows larger bores (conductor scales with bore radius only)

CCT is our highest priority

Excellent geometric field quality

Combines the best of our former program

- Subscale characteristics – simple and relatively inexpensive
- High field – scalable to highest fields (20T) and use of inserts



Our strategic goal is to achieve transformational magnets at lower cost and performing at higher field

1) Decrease operating margin
2) Minimize or eliminate training
3) Fully utilize grading
4) Flexible choice of bore diameter
5) Manufacturability (reliability & reproducibility)

Reduce effective $/T by a factor of 3

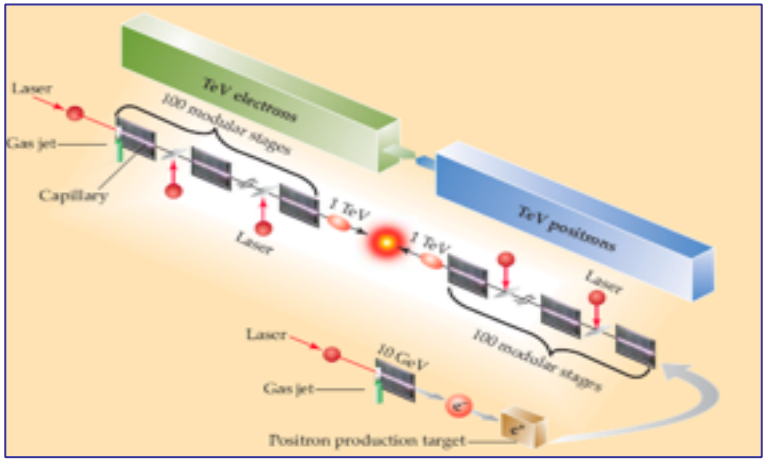
Goals of a program to realize this paradigm are

- Simplicity
- Reduce Stress

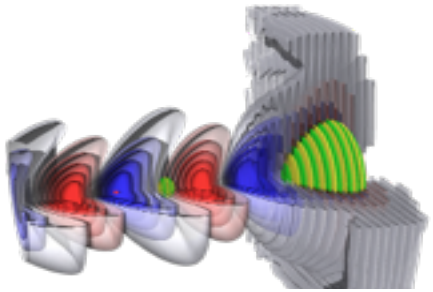
Combine baseline technology development with potentially high payoff disruptive technology development that can leapfrog the status quo

The third key thrust area is to develop compact-ultrahigh gradient, lower cost high energy accelerators

- Activities in BELLA Center and CBP

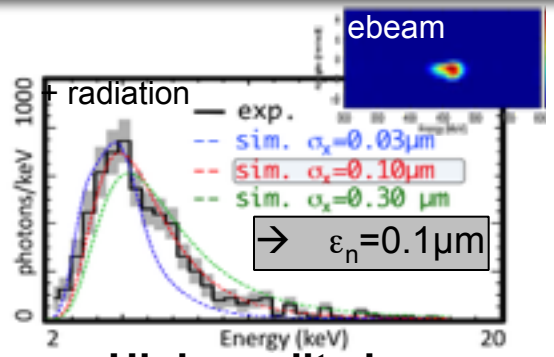


- Novel concepts towards future laser plasma accelerator based colliders
  - Experiments with TREX and BELLA lasers
  - Analytic theory to provide support and develop new ideas
  - Advanced computing towards near real-time modeling
  - See talks by Eric Esarey and WL

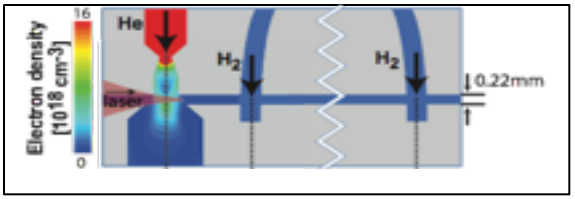


- Advanced modeling:
  - High performance tools to allow fast (near real-time), high fidelity accelerator modeling
  - CAMPA initiative (joint with SLAC and FNAL)

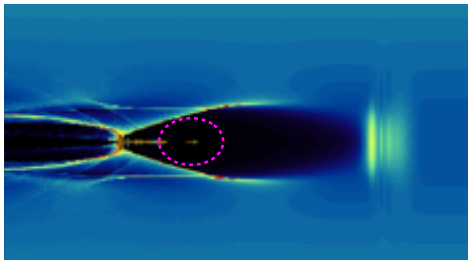
Program focuses on science and technology for laser plasma accelerators and applications



High quality beams



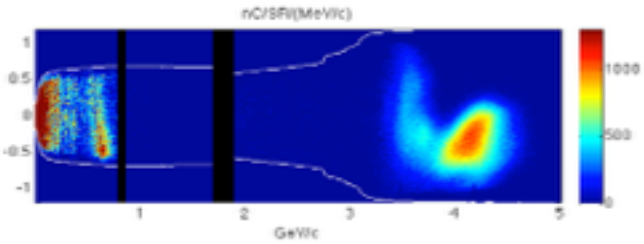
G. Plateau et al., PRL 2012
A.J. Gonsalves et al., Nature Phys. 2011
W.P. Leemans et al., Nature Phys. 2006
C.G.R. Geddes et al., Nature 2004



Theory/Modeling

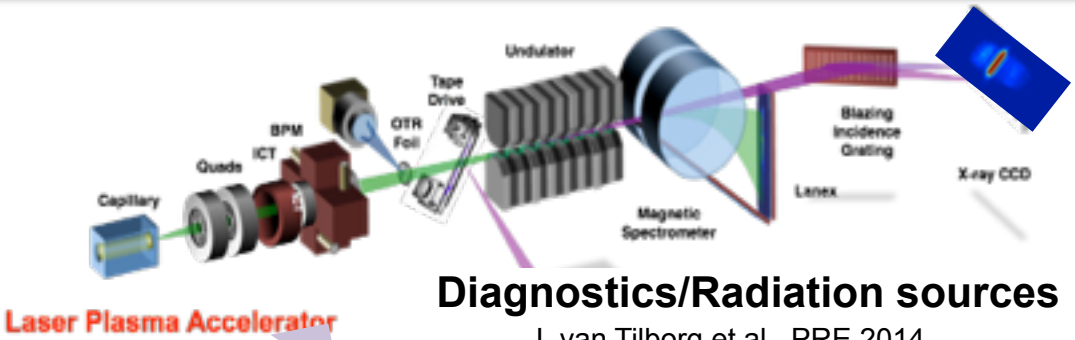
C. Benedetti et al., Phys. Plasmas 2014
L.L. Yu et al., PRL 2014
C.B. Schroeder et al., Phys. Plasmas 2013
C. Benedetti et al., Phys. Plasmas 2013

LOASIS/BELLA Program



Multi-GeV beams

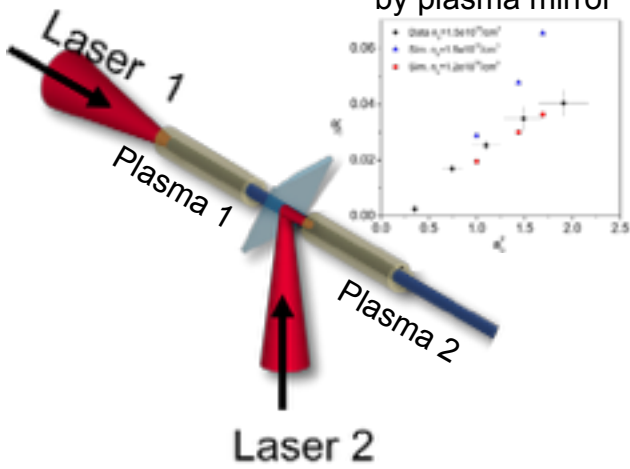
W.P. Leemans et al., submitted 2014
N. Bobrova et al., Phys. Plasmas 2013
C. Benedetti et al., Phys. Plasmas 2012



Diagnostics/Radiation sources

J. van Tilborg et al., PRE 2014
J. van Tilborg et al., Optics Lett 2013
B. Shaw et al., J. Applied Phys. 2013
L. Chen et al., PRL 2012

2nd stage powered by plasma mirror



Staging, optimized structures

S. Shiraishi et al., Phys. Plasmas 2013

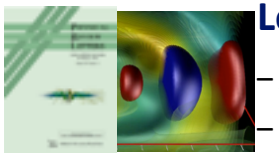
Accelerator Modeling at LBNL: Breadth & Innovation

Spans breadth of DOE/SC accelerators

- Intense multiphysics beam dynamics (space charge, beam-beam, e-cloud), laser-plasma accelerators, light sources, …
- Application to HEP, NP, BES, FES:

  Tevatron, MI, NML photo injector, LHC, SPS, PS, ILC, CESR-TA, BELLA, MAP, FRIB, RHIC, e-RHIC, ELIC, ALS, APS, SNS, LCLS, NSLS-II, LCLS-II, NDCX-II…
- Serving a worldwide user base
  - tens of users in U.S., Europe and Asia

Develops breakthrough algorithms



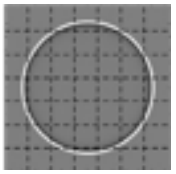
Lorentz boosted frame approach

- speedup up-to million times
- enabled first 3-D modeling of BELLA

2013 USPAS prize for achievement in accelerator phys. & tech.

Novel spectral Maxwell solver

- enables more accurate & stable simulations on very large computers



2014 NERSC achievement award for innovative use of HPC

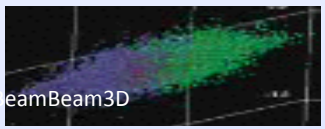
LBNL codes are relevant to P5 priorities

E.g.

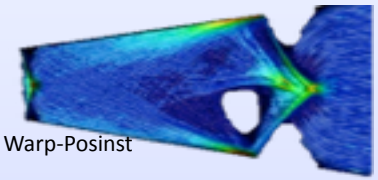
LBNL, LHC upgrade & ILC

- increased luminosity in PIP-II, SPS/LHC
- e-cloud modeling & mitigation

Modeling of beam-beam effects in Tevatron



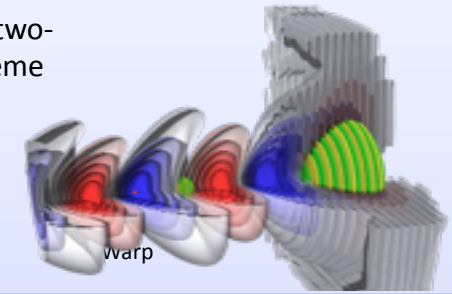
Modeling of e-cloud effects in 25 ns spacing bunch train in SPS



Advanced accelerators (K-BELLA)

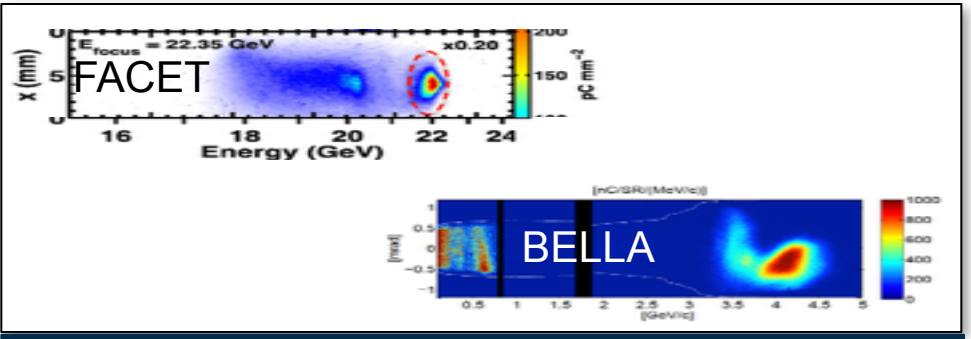
- generation, acceleration & transport of low emittance beams in laser plasma acc.

Modeling of novel two-color injection scheme

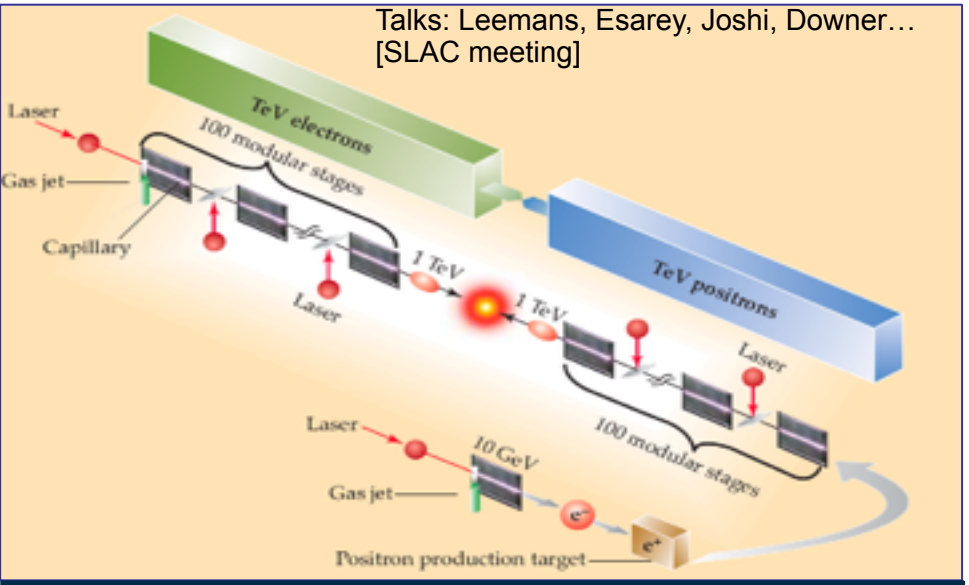


Future-generation accelerators at dramatically lower cost
Advances in modeling will offer new opportunities

Multi-GeV beam/laser plasma accelerators



Laser-plasma (LPA) collider concept:
100x 10 GeV stages (1m ea.), injector, focus, e+



Beam driven-plasma collider concept:
40x25 GeV stages (1m ea.), injector, focus, e+

- Accelerator: EM + plasma + beam
  - Current: PIC-MPI: meter scale, 10 GeV, ε~0.1μm
  - Goal: 100 m scale, 1 TeV, ε~0.01μm
    - Radiation, scattering, e+ production
- Target plasma + guide: hydrodynamics
  - Current: 1D MHD plasmas, commercial gas flow
  - Goal: 3D shaped plasmas + kHz operation + heat
- Beam transport + focusing
  - Goal: fs, kA beams, focusing and intera
- High average power lasers
  - Goal: materials, dammage, optical propagation

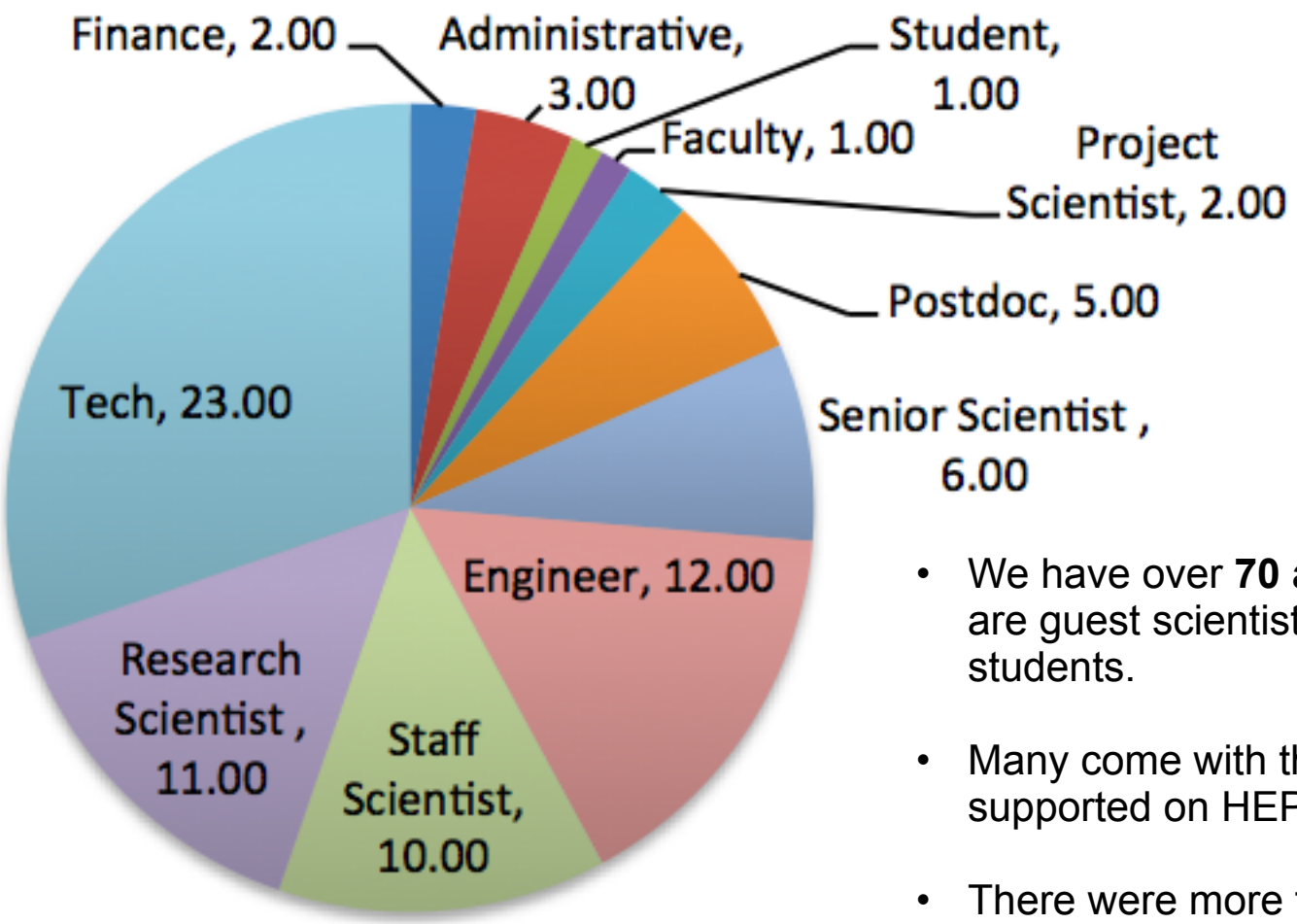
Advances in computers & algorithms:
- real-time of single stages on clusters,
- design of colliders on supercomputers.

LPA example

New initiatives aim at underpinning P5's vision for transformational R&D

- Advanced concepts that push the frontiers of accelerator technologies towards increased performance at reduced cost
  - *See Eric Esarey and WL's talks*
  - *BELLA Center and k-BELLA initiative*
- Magnets for future accelerators: radically increase performance, radically reduce cost
  - *See Soren Prestemon's talk at BNL*
  - *High field, low cost magnets; canted cosine theta approach at LBNL*
- Diagnosing and controlling "ultra"-beams
  - *See John Byrd's talk*
- High performance computing tools – modeling accelerators with (real-time) feedback for experiments
  - *See P. Spentzouris' talk at FNAL*
  - *CAMPA and "real-time" laser plasma accelerator modeling*

The ATAP headcount on HEP grants, including matrixed engineering staff is 76, excluding affiliates



~46 FTE support

- We have over **70 additional affiliates** who are guest scientists, post docs and/or students.
- Many come with their own funding or are supported on HEP or NSF campus grants.
- There were more than **23 students** in the division during FY13.

Training: students and postdoc

- Historically the division has had a large number of students and postdoc
- BELLA/LOASIS:
  - Since inception (1993) 27 postdoc, 52 grad students, 45 undergrad, 20 visiting scholars.
  - Three dissertation awards (two from APS, one from JPAS)
- CBP: (LOASIS was part of CBP till 2005) - typically 2-4 students/yr. Since 2010: 8 postdocs, 24 students
- SMP: Since 2011: 11 students
- State of the art laser facilities, magnet and RF development labs
- Exposure to an intellectually broad and stimulating environment, working on forefront problems
- USPAS teaching (Byrd, Venturini, Esarey, Schroeder, etc…)

Summary (and my personal thoughts)

- Accelerator science and technology needs continued innovation.
- Transformational opportunities need to be pursued to ensure longevity of the field through a bold vision for the future.
- The GARD portfolio should strongly support longer term R&D for (advanced) accelerators, subsystems and modeling that are transformational and that will lead to revolutionary new concepts that can sustain accelerator based particle physics into the next few decades.
  - A balance needs to be found where the "smaller" labs and universities in the US could have as primary goal to develop creative new ways of developing accelerators and training students, postdocs, and run user test facilities. We don't have big projects to build or facilities to run.
  - US competitiveness is at stake. Europe is launching many advanced acceleration groups (primarily laser driven but also beam driven). The investments are very significant and will put us at a strong disadvantage in competing for leadership on science and technology that has large potential economic benefits.

Backup slides

Background information on CBP, SMP and BELLA

- Staff
- Infrastructure

The HEP funding level of BELLA/LOASIS, CBP and Supercon is $14.407 M for FY14 and supports ~47 FTEs

LOASIS/BELLA Program:
- $3.342M (core) +$2M (BELLA ops) = $5.342M (~18 FTEs)

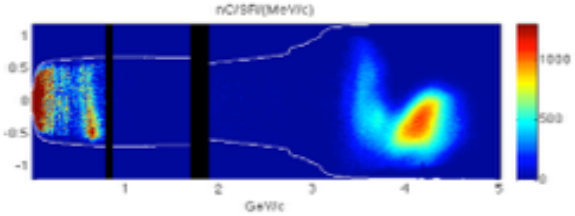
CBP:
- $1.77M (core)+$1.57M(MAP)+$0.42M(LARP)+$0.165M (SciDAC) =$3.942 M (~12 FTEs)

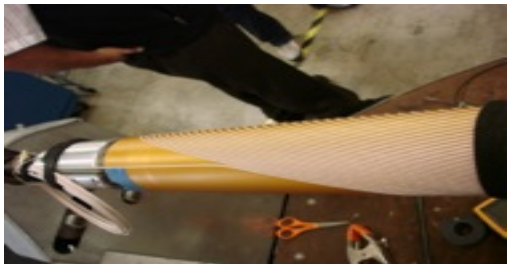
Supercon:
- $1.883M(core)+$2.684M (LARP)+$0.556M (conductor dev.)=$5.123M (~17 FTEs)

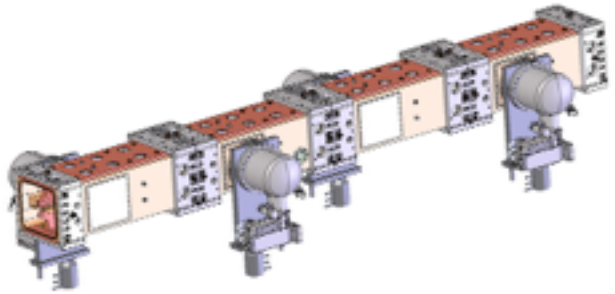
Scientists: ~50%
Techs/engineers: ~42%
Support staff: ~8%

Highlights of FY13 with HEP relevance

- Successful completion of BELLA project – received DOE Secretary Project Management award on March 2014
  - World record setting laser performance
- First experiments with BELLA reach new world record for laser plasma accelerators
  - 4.25 GeV in 9 cm
- Development of rigorous 3D magnetic and structural models of the CCT concept for high-field magnets, and first successful demonstration using Rutherford cable
- Magnet test facility upgrades (helium storage, new PS (pending), development of new diagnostics)
- Full RF and mechanical design of CW RFQ for PIP-II/ PXIE. Commissioning in 2015
- USPAS prize J.-L.Vay

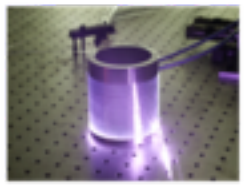


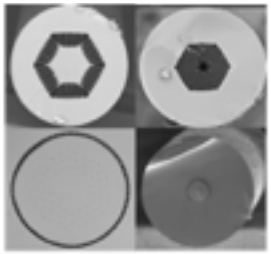


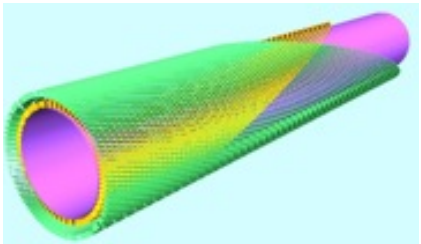


New initiatives at LBNL aim at disruptive technologies that will enable future HEP capabilities

- k-BELLA: high average power demonstrator at kW-level using a 1 kHz, 3 J/pulse laser for 1 GeV ebeam
  - Requires revolutionary new laser technology
    - Align with new stewardship program in HEP
    - Timing and synchronization (CBP)
  - FY15-FY20, $30-35 M
  - Planning and assessing space in 71
- Diagnosing and controlling “ultra”-beams
- Superconducting magnets at 20 T and at lower cost
  - Canted cosine theta magnets
  - Need base increase (Gourlay et al.)
- Frontier of computation in support of accelerator science and technology
  - Need base support for team (J.-L. Vay et al.)







BELLA Center
(formerly LOASIS Program)

Mission statement

Development of laser-plasma accelerator science and technology towards future high energy accelerators and training/education of the next generation accelerator scientists

GARD review was very supportive of BELLA/LOASIS

- LOASIS/BELLA team very effective in recruiting students.
  - In the past decade, 21 Ph.D. students did all or part of their work with LOASIS, along with 15 post-doctoral fellows, 21 undergraduates, and six senior visitors.
- Quality and impact of LOASIS/BELLA is unequaled by any other novel accelerator concepts group in the world.
  - Diligent about publishing, with 54 peer reviewed papers, many in prestigious journals such as Nature.

Unique among the GARD facilities reviewed here, the BELLA group has shown a good recognition of the long-term HEP program requirements and has incorporated activities aimed at meeting those requirements.

- Dedicated effort to get staging tests underway, both via experiments and modeling
- Close interaction of the simulation team (with input from CBP and other collaborators) and the experimental program
- BELLA is paying appropriate attention to practicality and the ultimate utility of the approach. To the extent that laser plasma acceleration proves to be a practical and useful technology for HEP, the innovations and technology development at this facility will prove to be essential, and provide the best prospect for showing what the approach can do.

LOASIS/BELLA staff (FY13-14)

Scientific Staff:


Wim Leemans


Csaba Toth


Kei Nakamura


Cameron Geddes


Eric Esarey


Carl Schroeder


Jean-Luc Vay


Anthony Gonsalves


Nicholas Matlis


Jeroen van Tilborg


Carlo Benedetti

Guest Researchers:


Stepan Bulanov


Prof. Andy Roberts

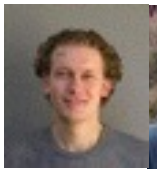
Postdoctoral Scholars:


Sven Steinke


Hann-Shin Mao

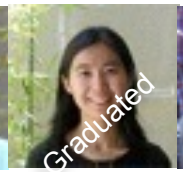
Names in blue are at U.C. Berkeley

PhD, Masters, undergrad students:


Joost Daniels

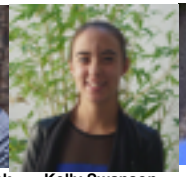

Daniel Mittelberger


Brian Shaw



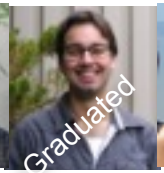
Satomi Shiraishi


Chris Pieronek

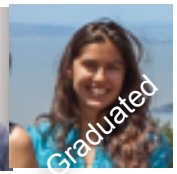

Kelly Swanson


Francesco Rossi


Patrick Lee



Koen Schakenraad



Sarah Breton


Sergei Rykovanov


Alexandre Bonatto

Engineering & Technical Support:


Don Syversrud


Dave Evans


Mark Kirkpatrick


Tyler Sipla


Nathan Ybarrolaza


Greg Mannino

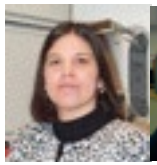

Aalhad Deshmukh

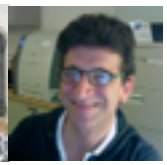

Art Magana


Joe Riley

Ken Sihler

Administrative Support:


Martha Condon


Wes Tabler

BELLA Center (LOASIS) has attracted many students, postdocs and visitors, and received prestigious awards

- Visiting Guest Researchers: Total – 20
- Postdoctoral Researchers: Total – 27
  - Some have started their own programs in other institutions
    - LOA (France), DESY (Germany), Shanghai (China)
  - Some went to other National Labs
    - LLNL, SLAC
  - Some went to universities
    - UCSD, Union College, Univ. Tolouse, Univ. Nebraska, …
- Graduate Students: Total – 52
  - UC Berkeley, U Chicago, Ecole Polytechnique, TU Eindhoven, Univ. of Paris, Peking Univ., Tokyo Univ, Oxford Univ., Univ. of Nevada,…
- Undergrads: Total – 45

- **Awards**:
  - 2006 APS-DPP, 2007 APS-DPB, 2007 JPAS outstanding dissertation awards
  - APS (3), IEEE (1), AAAS Fellow (1)
  - 2005 USPAS Prize
  - 2009 EO Lawrence award
  - 2010 J.M. Dawson award from APS-DPP for excellence in plasma physics
  - 2012 Advanced Accelerator Concept Prize
  - 2014 DOE Secretary's Achievement Award for BELLA Project

Although not a formal user facility, BELLA Center has many fruitful collaborations

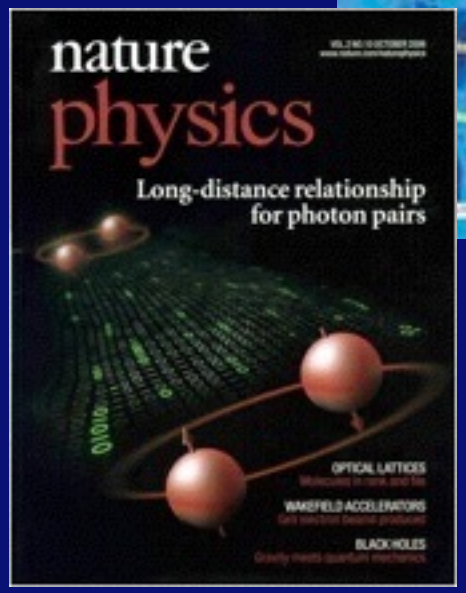
USA
J.Cary, B. Cowan, Tech-X, Boulder CO
M. Battaglia, UCSC
J. Rosenzweig, UCLA
D. Bruhwiler, RadiaSoft LLC, Boulder CO
T. Drummond, NERSC
P. Spentzouris, FNAL
M. Marinak, LLNL
J. Dawson, LLNL
C. Ng, Z. Huang, Y. Ding, SLAC
M. Downer, UT Austin
A. Galvanauskas, Univ. Michigan
S. Bulanov, UC Berkeley
A. Roberts, Minnesota State Unversity
M. Krishnan, AASC
A. Kanareykin, Euclid Techlab
A. Maksimchuk, A. G. R. Thomas, UMichigan
B. Godfrey, U Maryland

Topics:
Computation/simulation
Detectors
Lasers
Radio-isotope generation
Gas jets
High rep rate capillary discharges
High intensity laser-matter interactions
Ion acceleration
High harmonic generation

Overseas
F. Quere, CEA Saclay
S. Rykovanov, University of Jena
M. Chen, Shanghai Jiao Tong University
B. Hidding, Strathclyde/Hamburg
T. Stohlker, GSI, Germany
S. Hooker, Oxford University
S.V. Bulanov, JAEA Kansai Institute, Japan
G. Korn, ELI Beamlines, Czech Republic
F. Gruener, DESY and U. Hamburg
O. Albert, LOA, France
D. Margarone, ELI Beamlines, Prague, Czech Republic
N. A. Bobrova, Institute of Theoretical and Exp. Physics, Moscow, Russia
P. V. Sasorov, Keldysh Institute, Moscow
F. Pegoraro, University of Pisa, Pisa, Italy
F. Califano, University of Pisa, Pisa, Italy
T. Zh. Esirkepov, Kansai Photon Science Institute, JAEA Japan
M. Kando, J. K. Koga, A. S. Pirozhkov, T. Nakamura, JAEA, Japan
A. G. Zhidkov, Osaka University, Osaka, Japan
P. Chen, National Taiwan University, Taipei, Japan
N. B. Narozhny, V. D. Mur, Moscow Engineering Physics Institute, Moscow, Russia
V. S. Popov, Institute of Theoretical and Exp. Physics, Moscow, Russia

LOASIS Program Major Publications summary

- **Program: >310 journal articles, >7,500 citations**
- **29 refereed pubs in 2012-14, 25 conf pubs**
- **Publications in top journals**
  - Nature: 1 (cover story Sep 2004 -1,001 citations)
  - Nature Physics:2 (2006 - 859 citations, 2011)
  - Nature Comm: 1 (2013)
  - Science: 1 (1996 - 349 citations)
  - Reviews of Modern Physics: 1 (2009 - 390 citations)
  - Physics Today: 1
  - Phys. Rev. Lett.: 25
  - Phys. Rev. E: 11
  - Phys. Rev. ST-AB: 14
  - Phys. Plasmas: 39
  - Optics Letters: 4
  - IEEE Trans. Plasma Science: 4
  - Trans. Royal Society London: 1



The LOASIS Program/BELLA Center has world-class lasers and experimental systems

Operating since	Laser	Peak power	Pulse duration	Energy on target (J)	Rep rate (Hz)
1997	Chihuahua	~ 5TW	>40 fs	~0.3 +0.2	10
1999	Godzilla	<15 TW	>35 fs	~0.6	10
2005	TREX	<60 TW	>35 fs	~2.5	10
2013	BELLA	<1.3 PW	>37 fs	~40	1

Beam line name	Powered by	Experiments	FY14 funding
10 TW	Godzilla/ Chihuahua	Colliding pulse, THz, Betatron x-rays	Mothballed
Undulator line	TREX	Jet+cap experiments, single shot emittance and energy spread, cavity BPMs, betatron x-rays, beam transport, towards	Mothballed
Staging line	TREX	Staging of LPAs/deceleration-active	HEP/DNN
BELLA line	BELLA	10 GeV	HEP

The Center for Beam Physics

Mission: Understand and overcome fundamental challenges of next-generation accelerators and colliders.

CBP combines a highly talented and broadband staff of physicists and engineers in a creative environment to provide solutions for accelerator projects and serve as incubators for new concepts.

CBP Staff works on theory and simulation and on building hardware


Marco Venturini


Gregg Penn


Ji Qiang


Jean-Luc Vay


Jonathan Wurtele


Rob Ryne

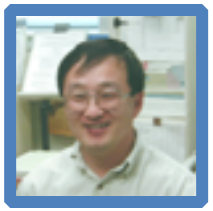
Admin


Wes Tabler

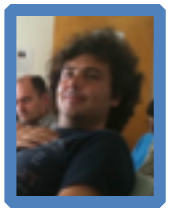
AFRD


Mike Zisman


Stefano De Santis


Derun Li


Gang Huang


Daniele Filippetto


John Byrd

ENG


Steve Virostek


Alan DeMello


Alex Ratti


Larry Doolittle


Russell Wilcox


Andrew Lambert


Kerri Campbell

Emeritus


Max Zolotorev


Andy Sessler
(in memoriam)


Bill Fawley


Miguel Furman


Bill Turner

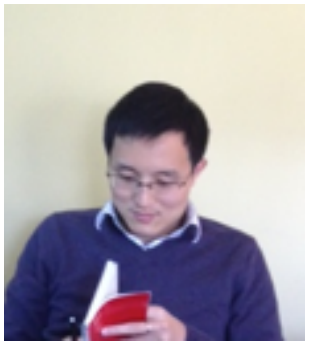

John Staples

CBP has HEP funding in FY14 for 1.5 postdocs and 2 students

Postdocs

Chad Mitchell, BES. Now LBNL Proj. Sci

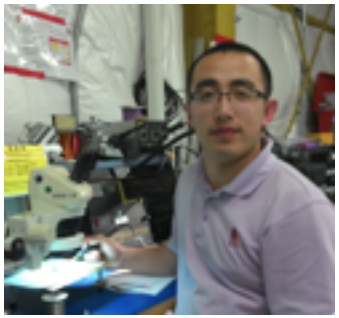
Tianhuan Luo, HEP



Houjun Qian, HEP/BES

Christos Papadopoulos, BES

Students



Jing Yang, Tsinghua Univ

Giuseppe Rizzelli, TBD

Since 2010, a total of 8 postdocs and 24 visiting students have been with CBP

We are addressing the GARD Review Spring 2013

CBP is a leader in accelerator modeling, and has historically been the incubator for a number of new accelerator ideas. The group has core competencies in beam dynamics, simulations, precision rf and laser control, rf and general electromagnetic modeling, and accelerator

One weakness of the CBP is the dearth of students. Both lack of funding and the concomitant need to focus on programmatic activities that are not well-suited to student participation are the root causes.

We are working on refocusing the Center for Beam Physics and discussing significant reorganization to ensure continued alignment onto HEP priorities

FY14 funds are insufficient and one staff member will be RIF'ed

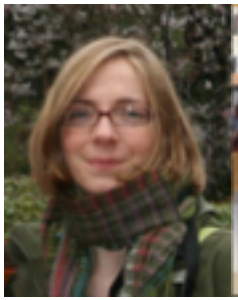
Superconducting Magnet Program

Mission statement

Explore the limits of superconducting magnet technology in field and performance

Superconducting Magnet Program Staff

Helene Felice | Daniel Dietderich | Ian Pong (Toohig) | GianLuca Sabbi | Maxim Martchevsky | Xiaorong Wang | Arno Godeke



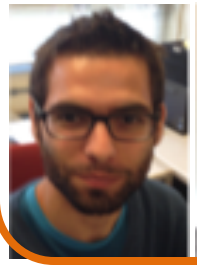




Franck Borgnolutti

Shlomo Caspi | Dan Cheng | Ray Hafalia | Etienne Rochepault | Diego Arbelaez | Marcos Turqueti

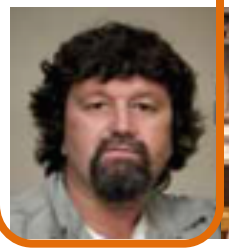


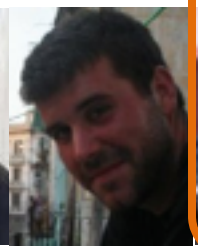


Currently on other projects: LBNL EG matrix helps maintain the staff, but they may not be available to the program in the future

Lucas Brouwer

Tom Lipton | John Pucci | Jim Swanson | Hugh Higley | Nick Heys | Robert Albright


LBNL Superconducting Magnet Program: A history of innovation and intellectual leadership

- World-record dipole fields in 3 geometries
- World-leading cabling facility
- Development of Nb_3Sn → creation of the LHC Accelerator Research Program (LARP)
- Creation of a "sub-scale" magnet program adopted internationally
- A versatile new key and bladder support structure concept developed for the RD and HD series magnets is now in broad use (baseline for LARP magnets)
- LARP magnet program leadership → adoption of Nb_3Sn technology as baseline for LHC luminosity upgrade
- 3D analysis tools integrated with advanced diagnostics that offer a realistic opportunity to understand and reduce or even eliminate magnet training

We have an opportunity to maintain DOE-HEP leadership in superconducting magnet technology and make a significant impact on the future of High Energy Physics

GARD review was very supportive of Supercon

- Strong core GARD program in this thrust area, extremely productive, permitting trials of new technical developments with minimal turnaround time and minimal costs.
- Consistently provided leadership to the entire U.S. program in the development of Nb_3Sn dipole technology, and is viewed as a key resource for future U.S. magnet R&D.
- Of the three GARD laboratories working in this thrust area, they appear to have the most sophisticated and integrated methods for conductor, cable, and magnet design and analysis.
- Recent efforts toward high field magnets have not been as successful as expected.

. . . .consolidate the block coil technology while at the same time performing a series of learning experiments to assess the challenges of the canted cosθ technology, ...